NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2824

EFFECTS OF INDEPENDENT VARIATIONS OF MACH NUMBER AND REYNOLDS NUMBER ON THE MAXIMUM LIFT COEFFICIENTS OF FOUR NACA 6-SERIES AIRFOIL SECTIONS

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SUMMARY

An investigation has been made in the Langley low-turbulence pressure tunnel to determine the effects of Mach number and Reynolds number on the maximum-lift characteristics of the NACA 65-006, 64-009, 64-210, and 64_2-215 airfoil sections in the smooth condition and in the condition with leading-edge roughness. The section lift characteristics were determined for Mach numbers ranging from 0.1 to approximately 0.5 at constant values of the Reynolds number. The Reynolds number range extended from 1.5×10^6 to 9.0×10^6.

For the airfoil sections with abrupt stalls, such as the NACA 64-210 at low Mach numbers, increases in Mach number (Reynolds number held constant) generally resulted in gradual stalls; whereas, variations of Mach number generally caused only small changes in the stalls for those airfoil sections, such as the NACA 64_2-215, with gradual stalls at low Mach numbers. With leading-edge roughness, the stall for each airfoil section was gradual and generally unaffected by variations of Mach number. The reduction in maximum section lift coefficient resulting from increasing the Mach number from 0.1 to 0.4 (Reynolds number held constant) may be as large as 0.4, depending upon the airfoil section. With leading-edge roughness, the maximum section lift coefficient was only slightly affected by variations of the Mach number between 0.1 and approximately 0.5. The Reynolds number effects as indicated by experimental data for smooth airfoil sections are dependent, in many cases, upon the manner in which the Mach number varies with Reynolds number. The prediction of aircraft low-speed performance characteristics from experimental data should include considerations of the interrelated effects of Mach number and Reynolds number on maximum lift if wing maximum lift coefficients approaching those of the smooth airfoil section are anticipated.

INTRODUCTION

In predicting the low-speed performance characteristics of aircraft with stalling speeds corresponding to Mach numbers of about 0.1, the maximum lift coefficient has been considered to be free of compressibility effects. High-speed performance requirements, however, have resulted in stalling speeds corresponding to Mach numbers of 0.2 or higher where the effects of compressibility may be significant. Inasmuch as the stalling speed is indicative of the landing speed and of the speeds involved in low-speed maneuvers, a knowledge of the effects of Mach number and Reynolds number on maximum lift is desirable. A series of investigations have been conducted by the National Advisory Committee for Aeronautics to study the effects of Mach number and Reynolds number on maximum lift coefficient (see refs. 1 to 8). In most of these investigations, the results were obtained from tests of three-dimensional models and the Mach number varied simultaneously with the Reynolds number. Investigations of two-dimensional models in which the Mach number is varied while the Reynolds number is held constant are needed to obtain an indication of the magnitude of the effects on two-dimensional sections.

An investigation has therefore been made in the Langley low-turbulence pressure tunnel of four airfoil sections ranging in thickness from 6 to 15 percent chord to determine the effects of Mach number when varied independently of the Reynolds number on the maximum lift coefficient for several constant values of the Reynolds number. The results of this investigation are presented in this paper.

The investigation consisted of measurements of the section lift characteristics from about zero lift to beyond the stall for the NACA 65-006, 64-009, 64-210, and 64_2-215 airfoil sections. The range of Mach number extended from 0.1 to approximately 0.5; whereas, the range of Reynolds number extended from 1.5×10^6 to 9.0×10^6. Data were obtained for the airfoil sections with aerodynamically smooth surfaces and with leading-edge roughness.

SYMBOLS

c_l — section lift coefficient, l/qc

$c_{l_{max}}$ — maximum section lift coefficient

$C_{L_{max}}$ — maximum wing lift coefficient

$\Delta c_{l_{max}}$	decrement of maximum section lift coefficient due to leading-edge roughness
α_o	section angle of attack, deg
R	Reynolds number, $\rho Vc/\mu$
M	free-stream Mach number, V/a
q	free-stream dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
V	free-stream velocity, ft/sec
ρ	free-stream mass density, slugs/cu ft
a	speed of sound in free stream, ft/sec
c	airfoil chord, ft
l	lift per unit span, lb/ft
μ	coefficient of viscosity, slugs/ft-sec

APPARATUS

The investigation reported herein was conducted in the Langley low-turbulence pressure tunnel. Since the publication of reference 9, which gives a general description of the tunnel, several modifications to the tunnel and added equipment have extended the operating range of the tunnel. The tunnel has a rectangular test section, $7\frac{1}{2}$ feet high by 3 feet wide, and can be operated at pressures ranging from approximately 1/5 atmosphere to 10 atmospheres absolute. Variations of Mach number and Reynolds number can be made independently by varying the airspeed and the stagnation pressure. The airfoil section lift characteristics for each of the two-dimensional models were determined from measurements of the integrated pressure reactions along the floor and ceiling of the tunnel test section.

Each of the four models tested in this investigation had a chord of 2 feet and was mounted with seals at the ends so as to span completely the tunnel test section. Ordinates for the NACA 65-006, 64-009, 64-210, and 64_2-215 airfoil sections are given in table I. The models had aerodynamically smooth surfaces for most of the tests. For the condition with leading-edge roughness, 0.011-inch-diameter carborundum grains were spread over a surface length of 0.08c back from the leading edge on both surfaces. The grains were thinly spread so as to cover from 5 to 10 percent of the included area (standard roughness used in ref. 10).

TESTS

Preliminary tests were made of each model in order to obtain a comparison of the lift characteristics of the present models with published data, and, in most cases, fair agreement was obtained between the results of preliminary tests and the results presented in reference 10. The model of the NACA 64-210 airfoil section was the last one tested, and the results of the preliminary tests indicated that, although the lift-curve slope was the same, the maximum section lift coefficient was about 0.1 lower than that obtained from previous tests. The addition of upper-surface fences extending from ahead of the leading edge to beyond the trailing edge, as shown in figure 1, increased the maximum section lift coefficient but also decreased the slope of the lift curve. Fences extending over the upper surface to the 0.33c station, as shown in figure 1, were then installed in an attempt to prevent separation from being induced by the tunnel-wall boundary layer and to minimize the pressure differential across each fence. As indicated by the data presented in figure 1, the installation of the shorter fences increased the slope of the lift curve to that obtained without fences and further increased the maximum section lift coefficient to approximately the value obtained in the investigation reported in reference 10.

The short fences were therefore used for the remaining tests of the model of the NACA 64-210 airfoil section. Lack of time prevented the performance of additional tests to determine whether the installation of similar fences on the other three models would also increase the maximum section lift coefficients. Additional investigations are needed to determine whether the low value of the maximum section lift coefficient obtained for the model of the NACA 64-210 airfoil section without fences was caused by the undetected imperfections in the surface finish, the absence of slots for bleeding the tunnel-wall boundary layers (the very small bleed slots were removed during the recent tunnel modification), or the extreme sensitivity of the maximum section lift coefficient of that airfoil section to small departures from true airfoil contour.

The section lift characteristics of each model in the smooth condition and for the condition with leading-edge roughness were determined for Mach numbers extending from 0.1 to about 0.5. The range of Reynolds number extended from 1.5×10^6 to 9.0×10^6. The range of angle of attack investigated for each model corresponded to a range of lift coefficient extending from about zero lift to beyond the stall. The test conditions for each model are listed in table II. A discussion of the methods used in correcting the data to free-air conditions is given in reference 9.

RESULTS AND DISCUSSION

The basic data consisting of the section lift characteristics for the four airfoil sections in the smooth condition and for the condition with leading-edge roughness are presented in figures 2 to 5. The effects of Mach number and Reynolds number on the maximum section lift coefficient are shown in figures 6 to 8.

Smooth Airfoils

Effect of Mach number for constant Reynolds number.- From the data presented in figure 2(a) it is apparent that variations of the Mach number between 0.1 and 0.4 resulted in only small changes in the shape of the lift-curve peak for the NACA 65-006 airfoil section. Increasing the section angle of attack of the NACA 65-006 airfoil section to slightly beyond that for stall generally caused only small changes in the section lift coefficient and most of the curves indicate that further increases in angle of attack resulted in a secondary rise in section lift coefficient. At Mach numbers of 0.20 and 0.21 and at Reynolds numbers of 6.0×10^6 and 9.0×10^6, respectively, the maximum values of the section lift coefficient were attained after the onset of separation. Similar secondary rises in the lift curves have been observed in tests of thin airfoils with sharp leading edges, as is the case for a flat plate, for Mach numbers as low as 0.1. The secondary rise in the lift curve for a flat plate is attributed to the increased loading over the rear part of the plate after the initial separation (ref. 11).

The lift curves for the NACA 64-009 airfoil section, presented in figure 3(a), indicate that, at a Mach number of 0.09, the stall was abrupt and increasing the Mach number beyond 0.26 resulted in a gradual stall. As was the case for the NACA 65-006 airfoil section, a secondary rise in section lift coefficient was obtained at a Mach number of 0.21 and the maximum value of the section lift coefficient was obtained after initial separation.

The lift curves for the NACA 64-210 airfoil section, presented in figure 4(a), indicate Mach number effects on the stalling characteristics similar to those observed in tests of the NACA 64-009 airfoil section.

The data for the NACA 64_2-215 airfoil section, presented in figure 5(a), indicate that gradual stalls were obtained for all the Mach numbers investigated. The change in stalling characteristics of the NACA 64_2-215 airfoil section resulting from variations of the Mach number between 0.1 and 0.4 were considerably less than the changes in stall obtained for the thinner airfoil sections. It is evident from the lift curves obtained for the four airfoil sections investigated that variations of the Mach number between 0.1 and 0.4 may result in marked changes in the airfoil stalling characteristics and should be considered in predicting aircraft performance and handling characteristics.

The data presented in parts (a) of figures 2 to 5 indicate that increasing the Mach number from 0.1 to 0.5 caused the slope of the lift curve, measured near zero lift, to increase slightly. Such an increase in lift-curve slope with increasing Mach number is indicated by theory. Changes in the section angle of attack for maximum section lift coefficient as a result of variations of Mach number were more apparent for the cases where the stalls were abrupt than for those cases where the stalls were gradual.

The variation of maximum section lift coefficient with Mach number for each of the four airfoil sections investigated is shown in figure 6(a). It is apparent from these data that the variation of maximum section lift coefficient with Mach number depends upon the airfoil section and to some extent upon Reynolds number. The maximum section lift coefficient of the NACA 65-006 airfoil section was essentially independent of the Mach number except for the previously discussed increase in section lift coefficient attained after the onset of separation at a Mach number of about 0.2. If the section lift coefficient corresponding to the onset of separation had been used as the maximum section lift coefficient for that Mach number, the variation of maximum section lift coefficient with Mach number would be considerably smaller. Increasing the Mach number from 0.1 to 0.4 caused the maximum section lift coefficient of the NACA 64-009 airfoil section to decrease by approximately 0.2.

The maximum section lift coefficient of the NACA 64-210 airfoil section decreased as much as 0.4 as a result of increasing the Mach number from 0.1 to 0.4. The knee of the curve of maximum section lift coefficient against Mach number coincides with the change from an abrupt stall to a more gradual stall. The maximum section lift coefficient of the NACA 64_2-215 airfoil section decreased approximately 0.2 as the Mach number increased from 0.1 to 0.4. The decrease was nearly the same as that obtained for the NACA 64-009 airfoil section but only about half of that obtained for the NACA 64-210 airfoil section.

Effect of Reynolds number for constant Mach number.- The effects of variations of the Reynolds number on the stalling characteristics were generally small for the range of Reynolds number investigated, as indicated by the data presented in parts (a) of figures 2 to 5. Increasing the Reynolds number up to 9.0×10^6, however, had a tendency to reduce the abruptness of the stall for the NACA 64-210 airfoil section (fig. 4(a)). The slope of the lift curve for each of the four airfoil sections investigated, as might be expected, was generally not affected to any large extent by variations of the Reynolds number.

The variations of maximum section lift coefficient with Reynolds number for the airfoil sections in the smooth condition are presented for constant values of the Mach number in figure 7. The maximum section lift coefficient of the NACA 65-006 airfoil section was nearly independent of the Reynolds number for each of the Mach numbers investigated. In the investigation reported in reference 12, it was found that, although the maximum section lift coefficient of the NACA 65-006 airfoil section was nearly constant for Reynolds numbers between 3×10^6 and 9×10^6, increasing the Reynolds number to 25×10^6 with slight variations of Mach number increased the maximum section lift coefficient at a low Mach number by approximately 0.1. (Although the effects of Reynolds number on the maximum section lift coefficient of the NACA 64-009 airfoil section were not investigated in the present investigation, data indicating the effects of varying the Reynolds number from 3×10^6 to 25×10^6 on the maximum lift coefficient of the NACA 64-009 airfoil section are presented in ref. 12.)

The data presented in figure 7 indicate that the maximum section lift coefficient of the NACA 64-210 airfoil section increased with increasing Reynolds number throughout the range of Reynolds number investigated. The manner in which the maximum section lift coefficient of the NACA 64-210 airfoil section varied with Reynolds number depended markedly upon the Mach number.

The maximum section lift coefficient of the NACA 64_2-215 airfoil section, presented in figure 7, generally increased with increasing Reynolds number for Reynolds numbers between 3.0×10^6 and 9.0×10^6. The manner in which the maximum section lift coefficient varied with Reynolds number was nearly consistent for all the Mach numbers investigated as compared with that for the NACA 64-210 airfoil section.

Effect of simultaneous variations of Mach number and Reynolds number.- In order to illustrate the variation of scale effects on maximum section lift coefficient, three variations of Mach number with Reynolds number were assumed as shown in figure 8(a). Condition 1 is approximately that for a 2-foot-chord wing in a wind tunnel at atmospheric pressure. Condition 2 is approximately that for a 2-foot-chord model in a wind tunnel at a pressure of 2 atmospheres absolute. Condition 3 represents one of the conditions that can be obtained with a 2-foot-chord model in the Langley low-turbulence pressure tunnel by regulating the pressure. The variation of maximum section lift coefficient with Reynolds number for the NACA 64-210 airfoil section for these conditions is presented in figure 8(b). The data presented in this figure show that the scale effects as indicated by experimental data can depend to a large extent on the manner in which the Mach number varies with the Reynolds number. The curve for condition 1 is markedly different from those for conditions 2 and 3. Reducing the variation of Mach number with Reynolds number from condition 1 to condition 2 resulted in a variation of maximum section lift coefficient with Reynolds number that was nearly the same as that for the condition of constant Mach number for a large range of Reynolds number. If it is expected that wing maximum lift coefficients approaching those of smooth airfoil sections will be realized on operational aircraft, the predicted aircraft low-speed performance characteristics may depend to a marked extent on whether the interrelated effects of Mach number and Reynolds number were considered.

Data indicating the interrelated effects of Mach number and Reynolds number on a wing utilizing the NACA 64-210 airfoil section are presented in references 7 and 13. The variation of Mach number with Reynolds number for the investigations reported in these references is presented in figure 9(a). The variation of maximum wing lift coefficient with Reynolds number, also obtained from these references, is presented in figure 9(b). Also shown in figure 9(b) is the variation of maximum section lift coefficient with Reynolds number for the NACA 64-210 airfoil section for the same Mach numbers as those used in the investigation of the wing reported in reference 13. The agreement between the airfoil-section data with those obtained from tests of the wing at a pressure of 33 pounds per square inch absolute can be considered good inasmuch as some of the small differences can be attributed to three-dimensional effects. A marked discrepancy, however, is evident between the airfoil maximum section lift coefficients and the wing maximum lift coefficients for atmospheric pressure for Reynolds numbers up to about 4×10^6 (fig. 9(c)). At Reynolds numbers higher than about 4×10^6, the wing data for atmospheric pressure are nearly in agreement with those obtained from two-dimensional tests. An explanation of the differences in the flow conditions causing such a marked disagreement between the wing maximum lift coefficients for atmospheric pressure and the airfoil maximum section lift coefficients is not available at present.

Comparison with previously published data.- Section aerodynamic data for the four airfoil sections investigated have been presented for Reynolds numbers of 3×10^6, 6×10^6, and 9×10^6 in reference 10. The approximate Mach numbers corresponding to those Reynolds numbers are indicated by the symbols in figure 10(a). These approximate Mach numbers, which were generally used in the investigation reported in reference 10, are such that the effects of compressibility on the maximum section lift coefficient are small for the corresponding Reynolds numbers as indicated by the data presented in figure 6.

A comparison of the maximum section lift coefficients obtained from the present investigation with those obtained from reference 10 for approximately the same Mach numbers is presented in figure 10(b). The maximum section lift coefficients obtained for the models used in the present investigation were generally slightly lower than those of the models used in the investigation reported in reference 10. The best agreement between the two sets of data was obtained for the NACA 64-210 airfoil section with fences. Some of the differences in the maximum section lift coefficients obtained from the two investigations might be caused by very small differences in the airfoil nose contour of the present models as compared with the models previously tested.

Rough Airfoils

Effect of Mach number for constant Reynolds number.- The data for the four airfoil sections investigated with leading-edge roughness, presented in parts (b) of figures 2 to 5 indicate that variations of the Mach number between 0.1 and 0.5 for a constant Reynolds number caused no marked changes in the stalling characteristics, and that all the stalls were gradual. In accordance with the discussion of flow phenomena at maximum lift in reference 12, a gradual stall might be expected with leading-edge roughness inasmuch as the stall usually results from a gradual forward movement of the separated turbulent boundary layer from the trailing edge. The variation of maximum section lift coefficient with Mach number was small in comparison with the variation obtained for the smooth condition (fig. 6). The fact that variation of Mach number had larger effects on the maximum lift for the smooth condition than on the maximum lift for the rough condition might be expected from consideration of the high local velocities associated with the maximum lift of thin smooth airfoil sections.

The effect of leading-edge roughness on the maximum section lift coefficient can be determined from a comparison of the data obtained for the smooth condition (fig. 6(a)) with those obtained at the same Mach number with leading-edge roughness (fig. 6(b)). For the airfoils with thicknesses of 0.09c, 0.10c, and 0.15c, the decrement of maximum section lift coefficient due to leading-edge roughness generally decreased as the Mach number increased. Leading-edge roughness on the airfoil section with a thickness of 0.06c generally caused a slight increase in maximum section lift coefficient.

Effect of Reynolds number for constant Mach number.- The effect of varying the Reynolds number on the stalling characteristics while maintaining a constant value of the Mach number is indicated by the data presented in parts (b) of figures 2 to 5. The data indicate that, with leading-edge roughness, the type of stall and the slope of the lift curve were not appreciably affected by variations of the Reynolds number within the range investigated. The maximum section lift coefficients for the four airfoil sections investigated, presented in figure 6(b), were nearly independent of the Reynolds number. Data for the NACA 63-009 airfoil section in reference 12 indicate that the maximum section lift coefficient for that airfoil section with leading-edge roughness was nearly constant for Reynolds numbers between 6×10^6, which was the lowest value investigated, to 25×10^6.

Effect of simultaneous variations of Mach number and Reynolds number.- The variation of maximum section lift coefficient of the NACA 64-210 airfoil section for three conditions of varying Mach number is presented in figure 8(c). The data presented in figure 8(c) indicate that, for the NACA 64-210 airfoil section with leading-edge roughness, the variation of maximum section lift coefficient with Reynolds number was nearly the same regardless of how the Mach number varied with Reynolds number, if the Mach number was less than 0.5. From the data for the other three airfoil sections with leading-edge roughness (fig.6(b)), it can be seen that the manner in which the Mach number varied with Reynolds number would also have only small effects on the variation of maximum section lift coefficient with Reynolds number. A comparison of the data presented in figure 8(c) with those presented in figure 8(b) indicates that the interrelated effects of Mach number and Reynolds number on maximum lift for the rough airfoil at Mach numbers less than 0.5 are very small as compared with those for the smooth airfoil section.

Comparison with previously published data.- The maximum section lift coefficients obtained with leading-edge roughness for a Reynolds number of 6×10^6 and a Mach number of 0.10 and the decrements of maximum section lift coefficient due to leading-edge roughness for a Reynolds number of 6×10^6 are compared with values obtained from reference 10 in the following table:

Airfoil section	Present investigation		Reference 10	
	$c_{l_{max}}$	$\Delta c_{l_{max}}$	$c_{l_{max}}$	$\Delta c_{l_{max}}$
NACA 65-006	0.86	-0.08	0.92	-0.08
NACA 64-009	.86	.16	.90	.18
NACA 64-210	.97	.44	1.04	.40
NACA 64_2-215	1.11	.35	1.21	.34

In general, the maximum section lift coefficients obtained from the two investigations are in agreement by the same amount as were the data for the smooth airfoil sections (fig. 10). The decrements of maximum section lift coefficient due to leading-edge roughness were generally in very good agreement with the values obtained from reference 10.

CONCLUSIONS

An investigation has been made in the Langley low-turbulence pressure tunnel to determine the effect of varying the free-stream Mach number from 0.1 to approximately 0.5 for constant values of the Reynolds number ranging from 1.5×10^6 to 9.0×10^6 on the maximum-lift characteristics of the NACA 65-006, 64-009, 64-210, and 64_2-215 airfoil sections in the smooth condition and in the condition with leading-edge roughness. The results of the investigation indicate the following conclusions:

1. For the airfoil sections with abrupt stalls, such as the NACA 64-210 at low Mach numbers, increases in Mach number (Reynolds number held constant) generally resulted in gradual stalls; whereas, variations of Mach number generally caused only small changes in the stalls for those airfoil sections such as the NACA 64_2-215 with gradual stalls at low Mach numbers. The stall for each airfoil section with leading-edge roughness was gradual and was generally unaffected by variations of Mach number.

2. The reduction in maximum section lift coefficient resulting from an increase in Mach number from 0.1 to 0.4 depended on the airfoil section and Reynolds number, was very small for the NACA 65-006 airfoil section, and ranged from 0.2 to 0.4 for the thicker airfoil sections. With leading-edge roughness, the maximum section lift coefficient was only slightly affected by increasing the Mach number from 0.1 to approximately 0.5.

3. The Reynolds number effects as indicated by experimental data for smooth airfoil sections are dependent, in many cases, upon the manner in which the Mach number varies with Reynolds number. Consequently, the prediction of aircraft low-speed performance characteristics should include considerations of the interrelated effects of Mach number and Reynolds number on maximum lift if wing maximum lift coefficients approaching those of the smooth airfoil section are anticipated.

4. The interrelated effects of Mach number and Reynolds number as indicated from investigations of full-span wings were not always in agreement with the effects indicated by data obtained from investigations of two-dimensional models. The reasons for the differences were not evident.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 3, 1952.

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TABLE I.- AIRFOIL SECTION ORDINATES

[Stations and ordinates given in percent of airfoil chord]

NACA 65-006

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.5	.476	.5	-.476
.75	.574	.75	-.574
1.25	.717	1.25	-.717
2.5	.956	2.5	-.956
5.0	1.310	5.0	-1.310
7.5	1.589	7.5	-1.589
10	1.824	10	-1.824
15	2.197	15	-2.197
20	2.482	20	-2.482
25	2.697	25	-2.697
30	2.852	30	-2.852
35	2.952	35	-2.952
40	2.998	40	-2.998
45	2.983	45	-2.983
50	2.900	50	-2.900
55	2.741	55	-2.741
60	2.518	60	-2.518
65	2.246	65	-2.246
70	1.935	70	-1.935
75	1.594	75	-1.594
80	1.233	80	-1.233
85	.865	85	-.865
90	.510	90	-.510
95	.195	95	-.195
100	0	100	0

L.E. radius: 0.240

NACA 64-009

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.50	.739	.50	-.739
.75	.892	.75	-.892
1.25	1.128	1.25	-1.128
2.5	1.533	2.5	-1.533
5.0	2.109	5.0	-2.109
7.5	2.543	7.5	-2.543
10	2.898	10	-2.898
15	3.455	15	-3.455
20	3.868	20	-3.868
25	4.170	25	-4.170
30	4.373	30	-4.373
35	4.479	35	-4.479
40	4.490	40	-4.490
45	4.364	45	-4.364
50	4.136	50	-4.136
55	3.826	55	-3.826
60	3.452	60	-3.452
65	3.026	65	-3.026
70	2.561	70	-2.561
75	2.069	75	-2.069
80	1.564	80	-1.564
85	1.069	85	-1.069
90	.611	90	-.611
95	.227	95	-.227
100	0	100	0

L.E. radius: 0.579

NACA 64-210

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.431	.867	.569	-.767
.673	1.056	.827	-.916
1.163	1.354	1.337	-1.140
2.401	1.884	2.599	-1.512
4.890	2.656	5.110	-2.024
7.387	3.248	7.613	-2.400
9.887	3.736	10.113	-2.702
14.894	4.514	15.106	-3.168
19.905	5.097	20.095	-3.505
24.919	5.533	25.081	-3.743
29.934	5.836	30.066	-3.892
34.951	6.010	35.049	-3.950
39.968	6.059	40.032	-3.917
44.985	5.938	45.015	-3.748
50.000	5.689	50.000	-3.483
55.014	5.333	54.987	-3.143
60.025	4.891	59.975	-2.749
65.033	4.375	64.967	-2.315
70.038	3.799	69.962	-1.855
75.040	3.176	74.960	-1.386
80.038	2.518	79.962	-.926
85.033	1.849	84.968	-.503
90.024	1.188	89.977	-.154
95.012	.564	94.988	.068
100.000	0	100.000	0

L.E. radius: 0.720
Slope of radius through L.E.: 0.084

NACA 64_2-215

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.399	1.254	.601	-1.154
.637	1.522	.863	-1.382
1.122	1.945	1.378	-1.731
2.353	2.710	2.647	-2.338
4.836	3.816	5.164	-3.184
7.331	4.661	7.669	-3.813
9.831	5.356	10.169	-4.322
14.840	6.456	15.160	-5.110
19.857	7.274	20.143	-5.682
24.878	7.879	25.122	-6.039
29.901	8.290	30.099	-6.346
34.926	8.512	35.074	-6.452
39.952	8.544	40.048	-6.402
44.977	8.319	45.023	-6.129
50.000	7.913	50.000	-5.707
55.020	7.361	54.980	-5.171
60.036	6.691	59.964	-4.549
65.048	5.925	64.952	-3.865
70.055	5.085	69.945	-3.141
75.058	4.191	74.942	-2.401
80.055	3.267	79.945	-1.675
85.046	2.349	84.954	-1.003
90.033	1.466	89.967	-.432
95.016	.662	94.984	-.030
100.000	0	100.000	0

L.E. radius: 1.590
Slope of radius through L.E.: 0.084

TABLE II.- TEST CONDITIONS

Airfoil section	Surface condition	Reynolds number	Range of Mach number	Figure
NACA 65-006	Smooth	3.0×10^6 6.0 9.0	0.10 to 0.37 .09 to .36 .11 to .39	2(a)
	Rough	3.0 6.0	.10 to .37 .14 to .36	2(b)
NACA 64-009	Smooth Rough	6.0 6.0	.09 to .47 .09 to .46	3(a) 3(b)
NACA 64-210	Smooth	1.5 2.5 3.0 4.5 6.0 9.0	.07 to .34 .08 to .24 .08 to .41 .08 to .33 .09 to .46 .10 to .37	4(a)
	Rough	1.5 2.5 3.0 4.5 6.0 9.0	.08 to .33 .08 to .20 .08 to .41 .07 to .35 .08 to .45 .10 to .38	4(b)
NACA 64_2-215	Smooth	3.0 6.0 9.0	.09 to .35 .09 to .42 .11 to .36	5(a)
	Rough	3.0 6.0 9.0	.09 to .36 .09 to .43 .11 to .36	5(b)

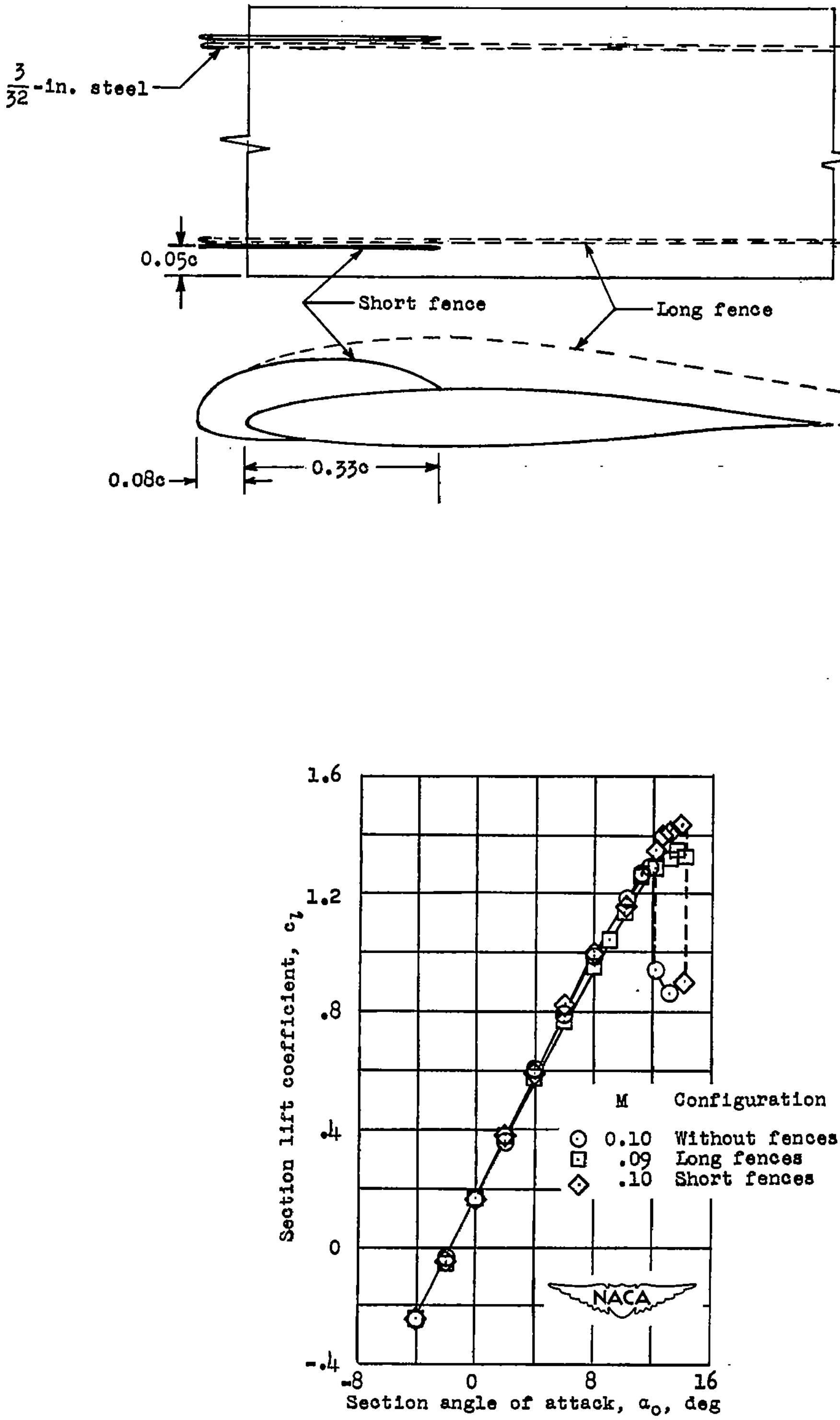
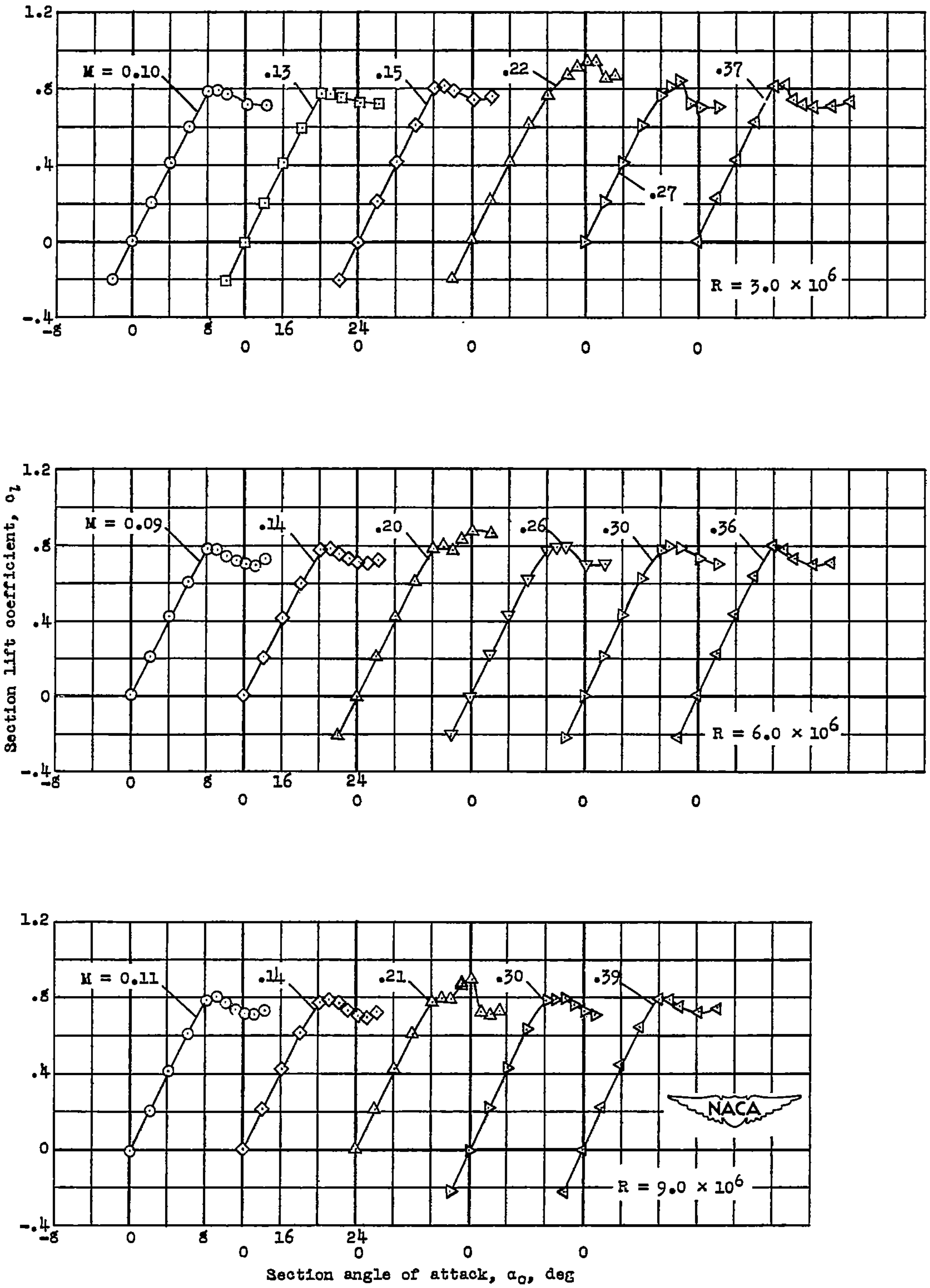
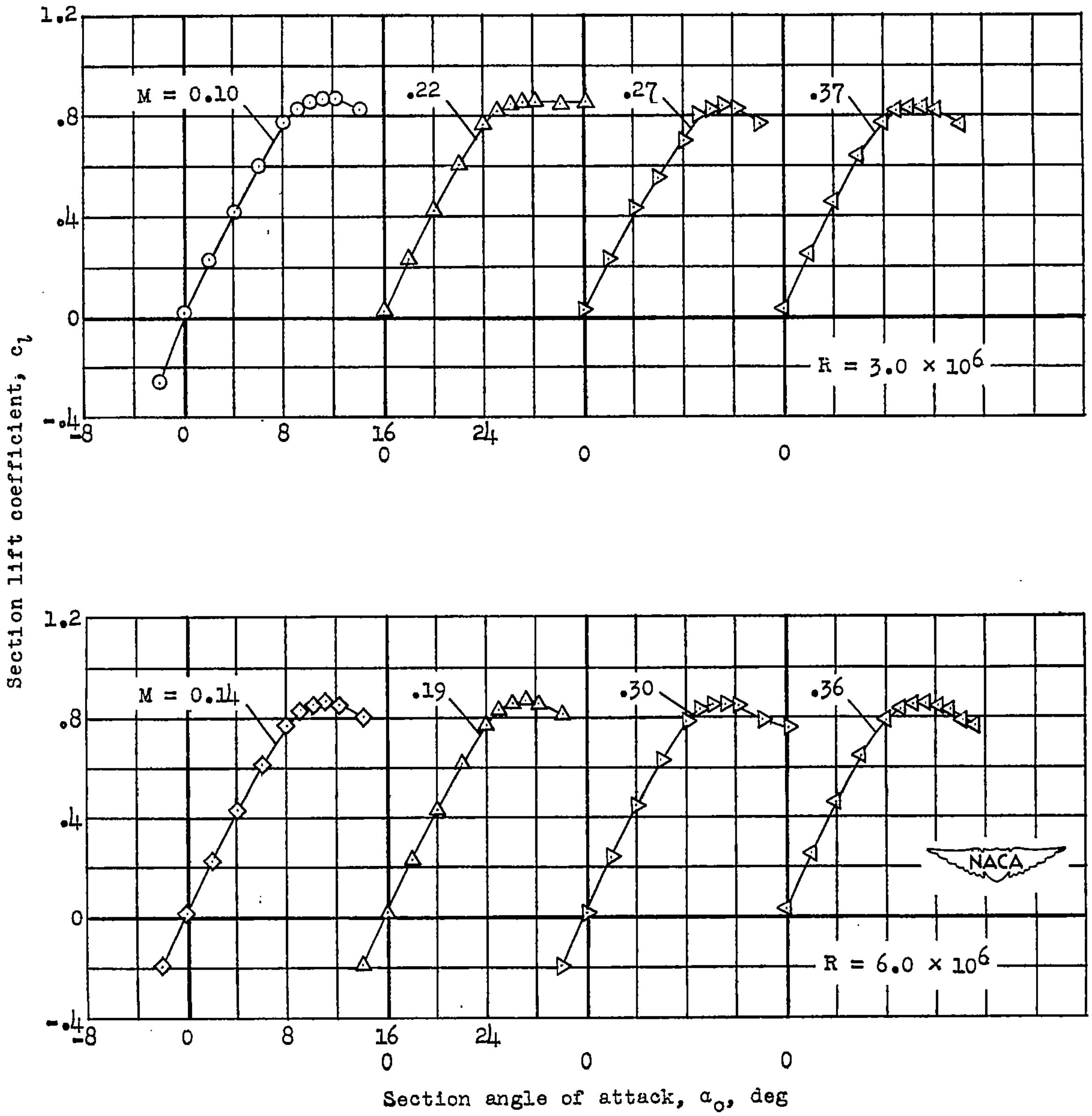


Figure 1.- Section lift characteristics of the NACA 64-210 airfoil section with and without fences. Smooth condition; $R = 3.0 \times 10^6$.



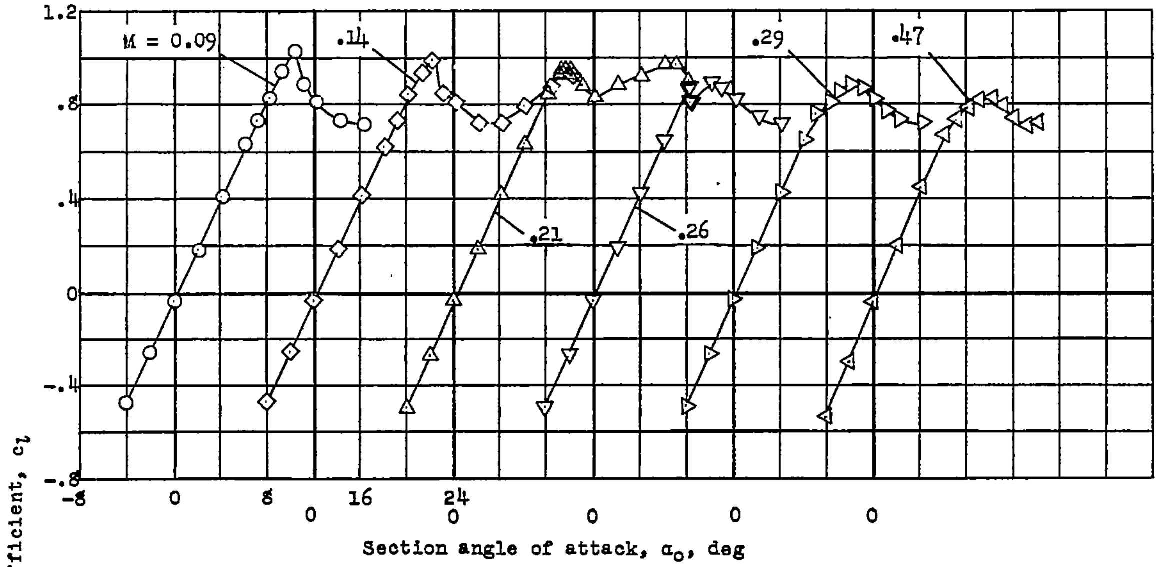
(a) Smooth condition.

Figure 2.- Section lift characteristics of the NACA 65-006 airfoil section at several free-stream Mach numbers and Reynolds numbers.

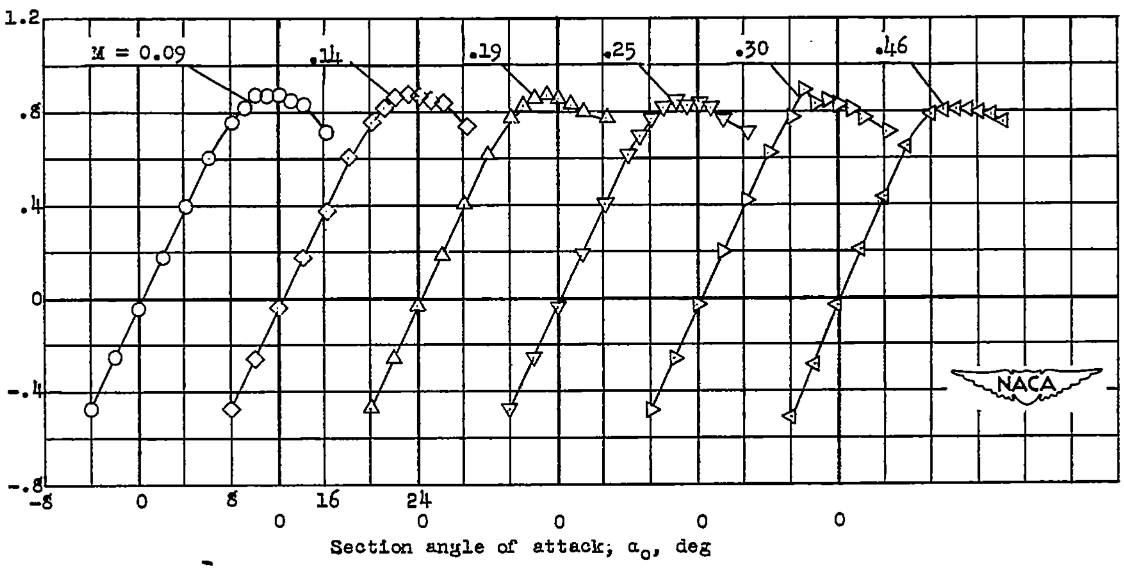


(b) Rough condition.

Figure 2.- Concluded.

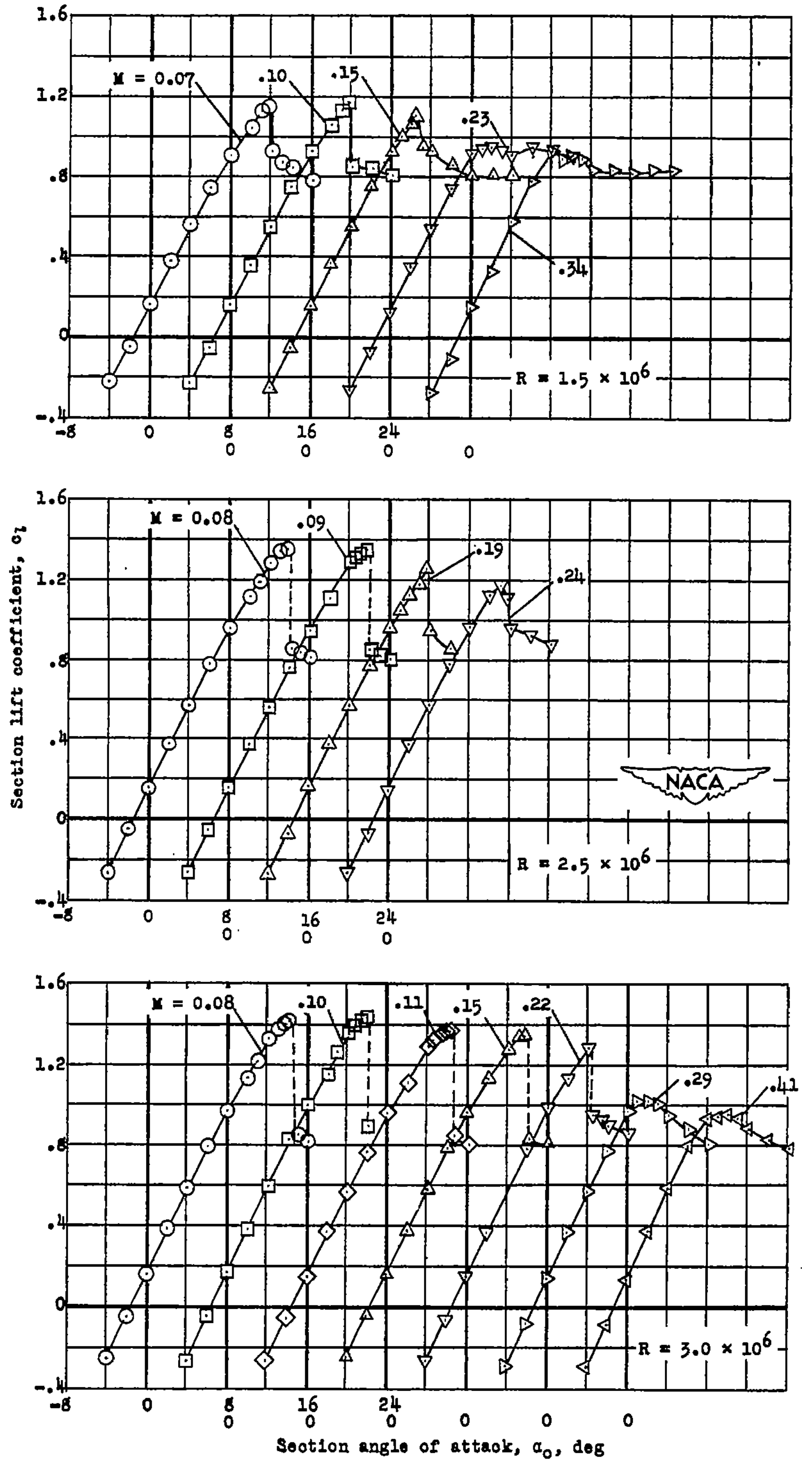


(a) Smooth condition.



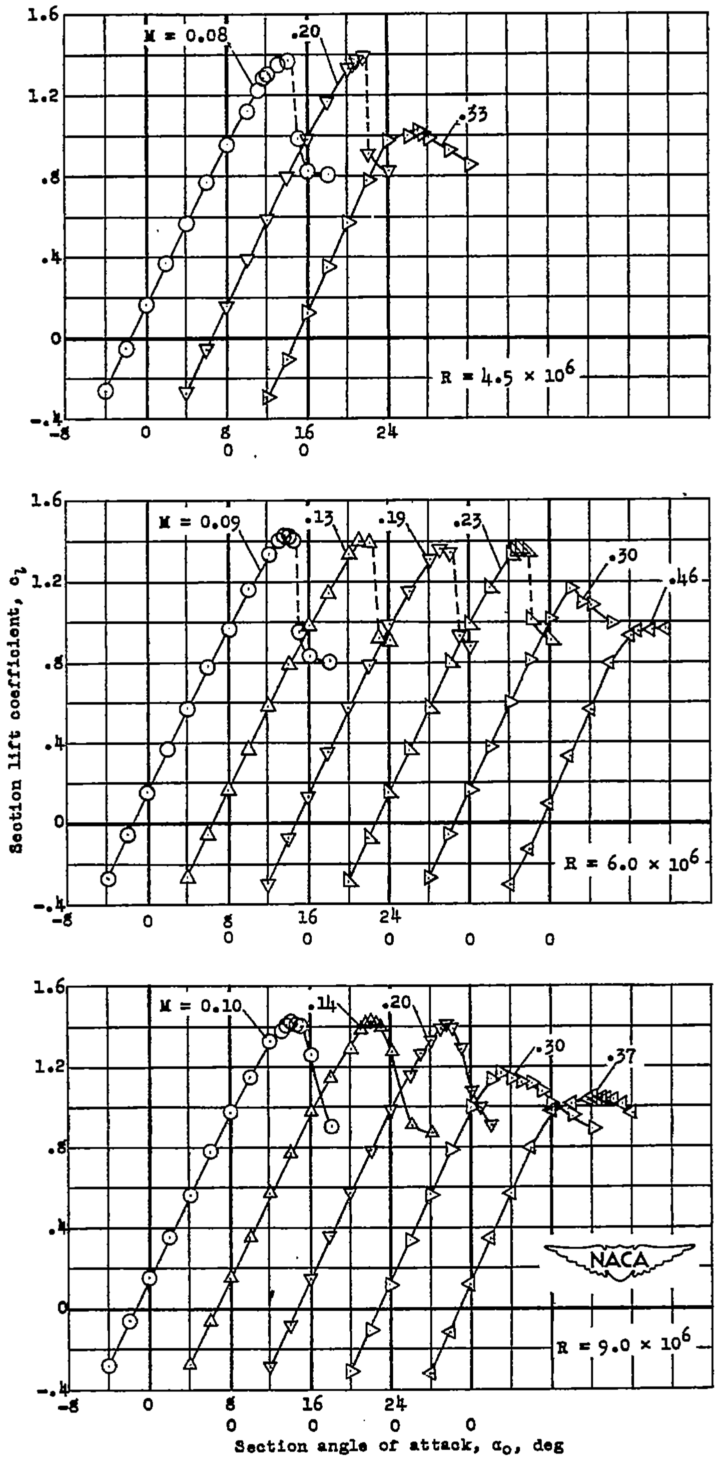
(b) Rough condition.

Figure 3.- Section lift characteristics of the NACA 64-009 airfoil section at several free-stream Mach numbers. $R = 6.0 \times 10^6$.



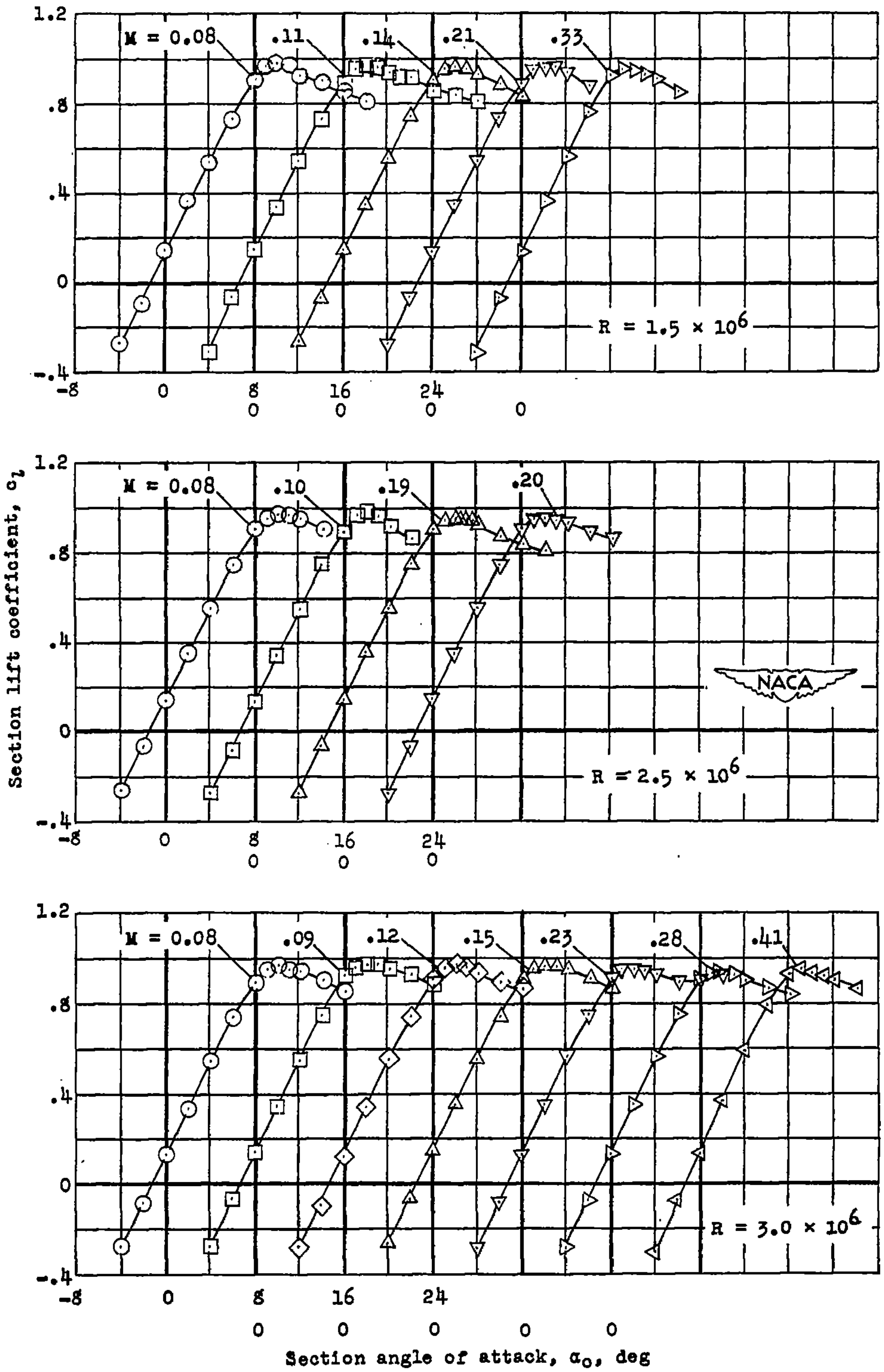
(a) Smooth condition.

Figure 4.- Section lift characteristics of the NACA 64-210 airfoil section at several free-stream Mach numbers and Reynolds numbers.



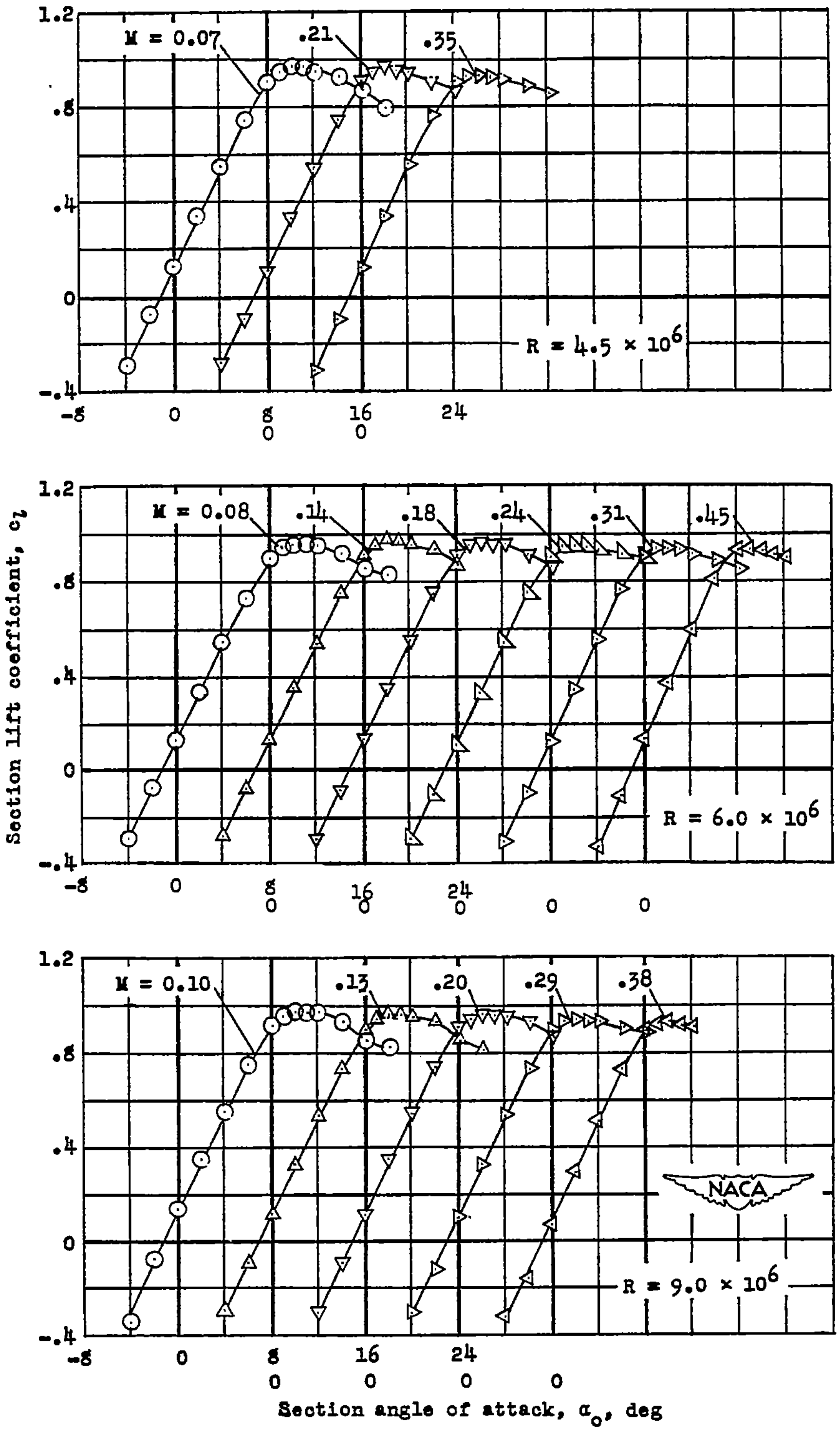
(a) Smooth condition. Concluded.

Figure 4.- Continued.



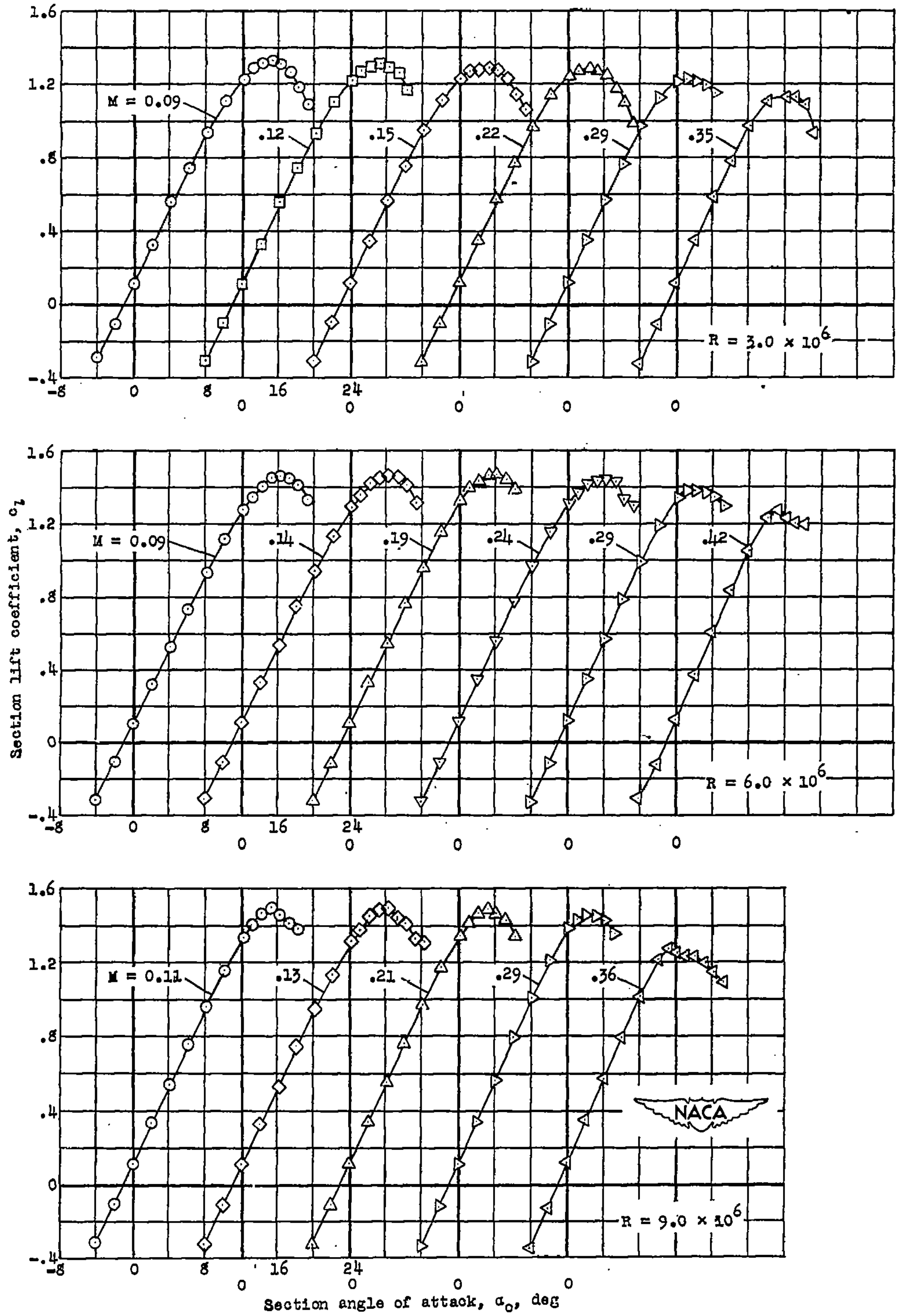
(b) Rough condition.

Figure 4.- Continued.



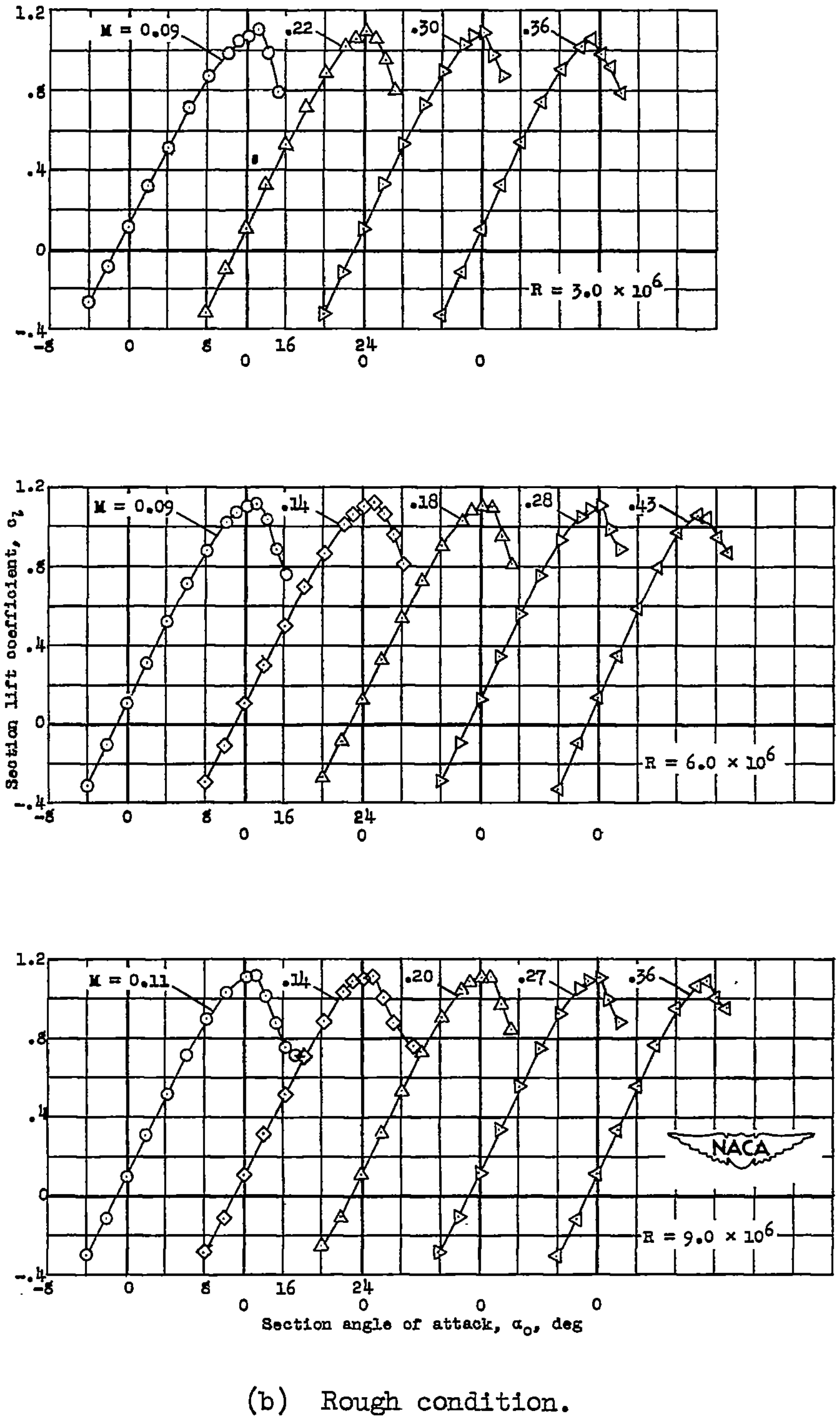
(b) Rough condition. Concluded.

Figure 4.- Concluded.



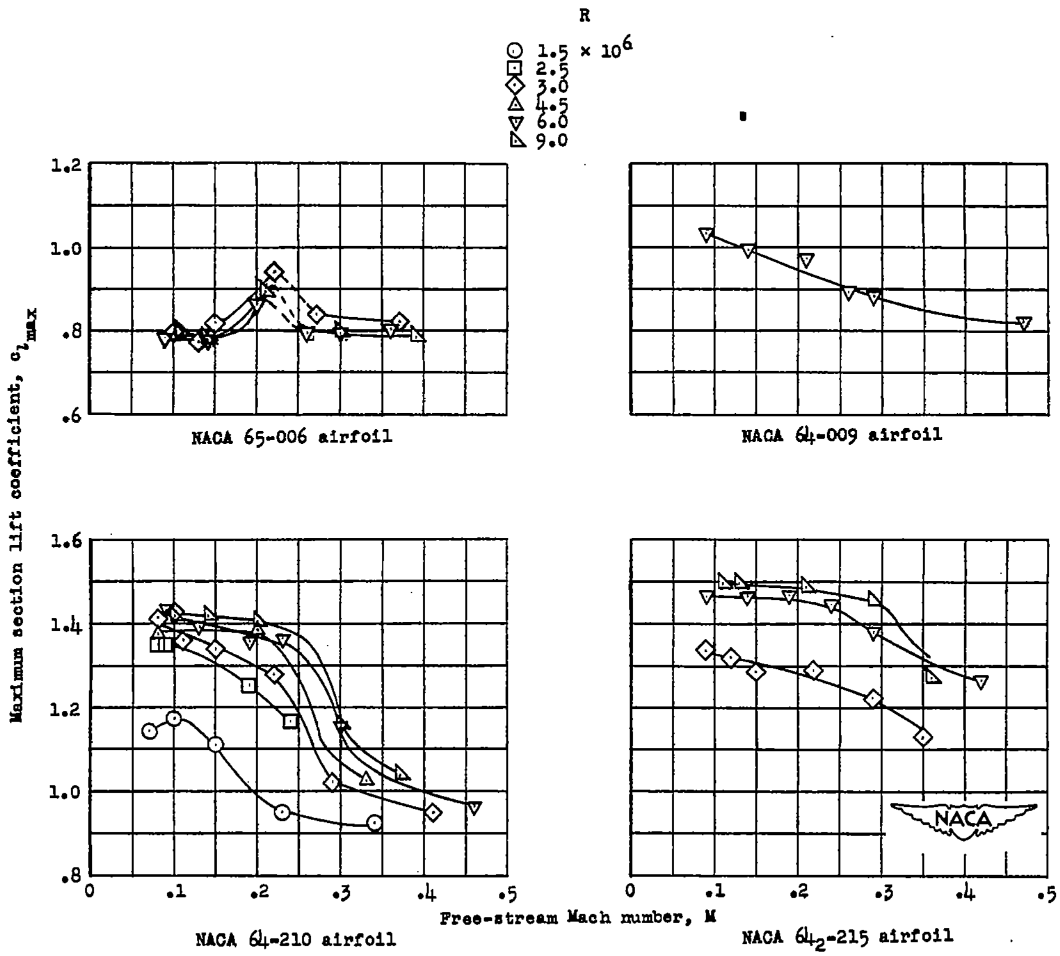
(a) Smooth condition.

Figure 5.- Section lift characteristics of the NACA 64_2-215 airfoil section at several free-stream Mach numbers and Reynolds numbers.



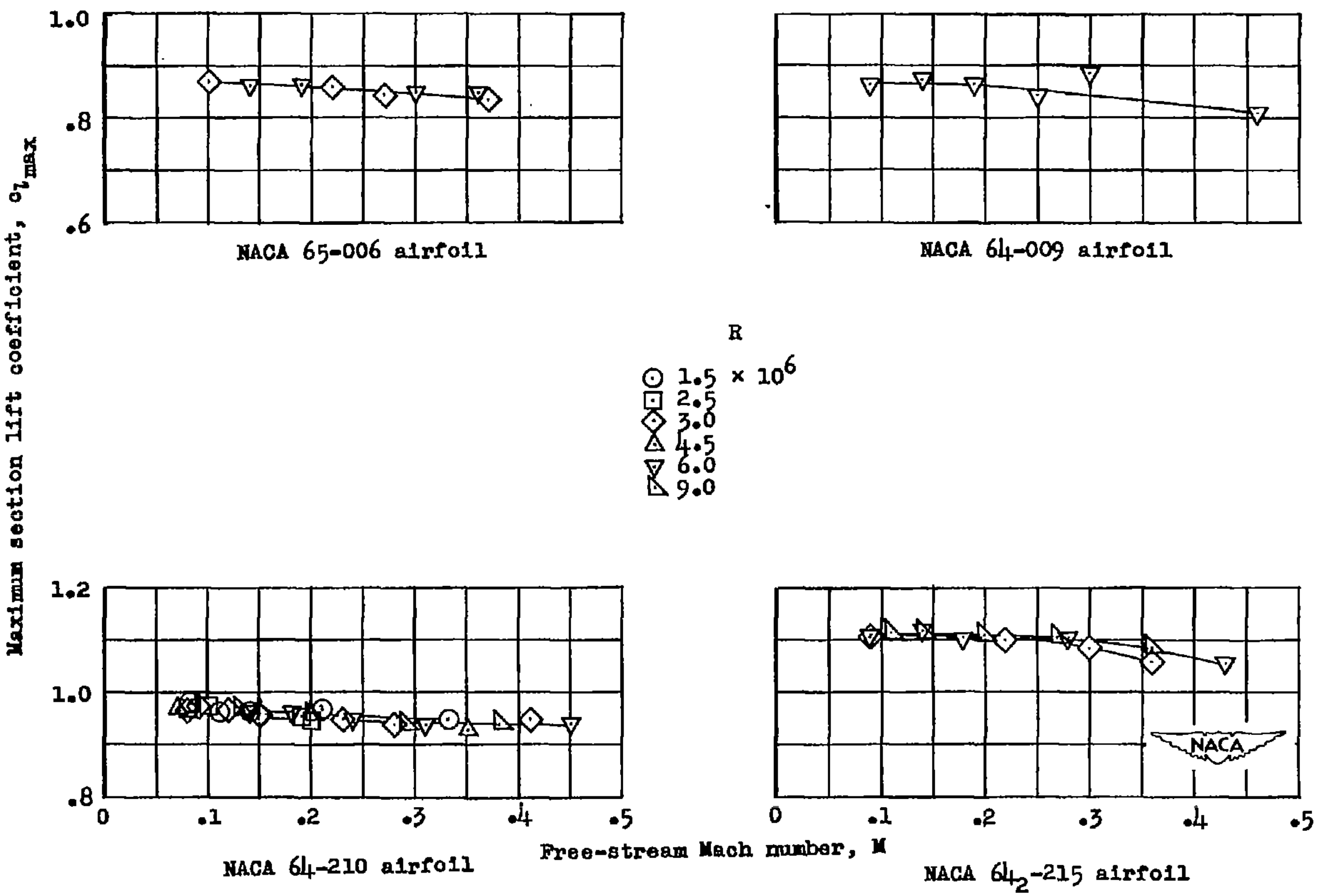
(b) Rough condition.

Figure 5.- Concluded.



(a) Smooth condition.

Figure 6.- Variation of maximum section lift coefficient with free-stream Mach number for several NACA 6-series airfoil sections at several Reynolds numbers.



(b) Rough condition.

Figure 6.- Concluded.

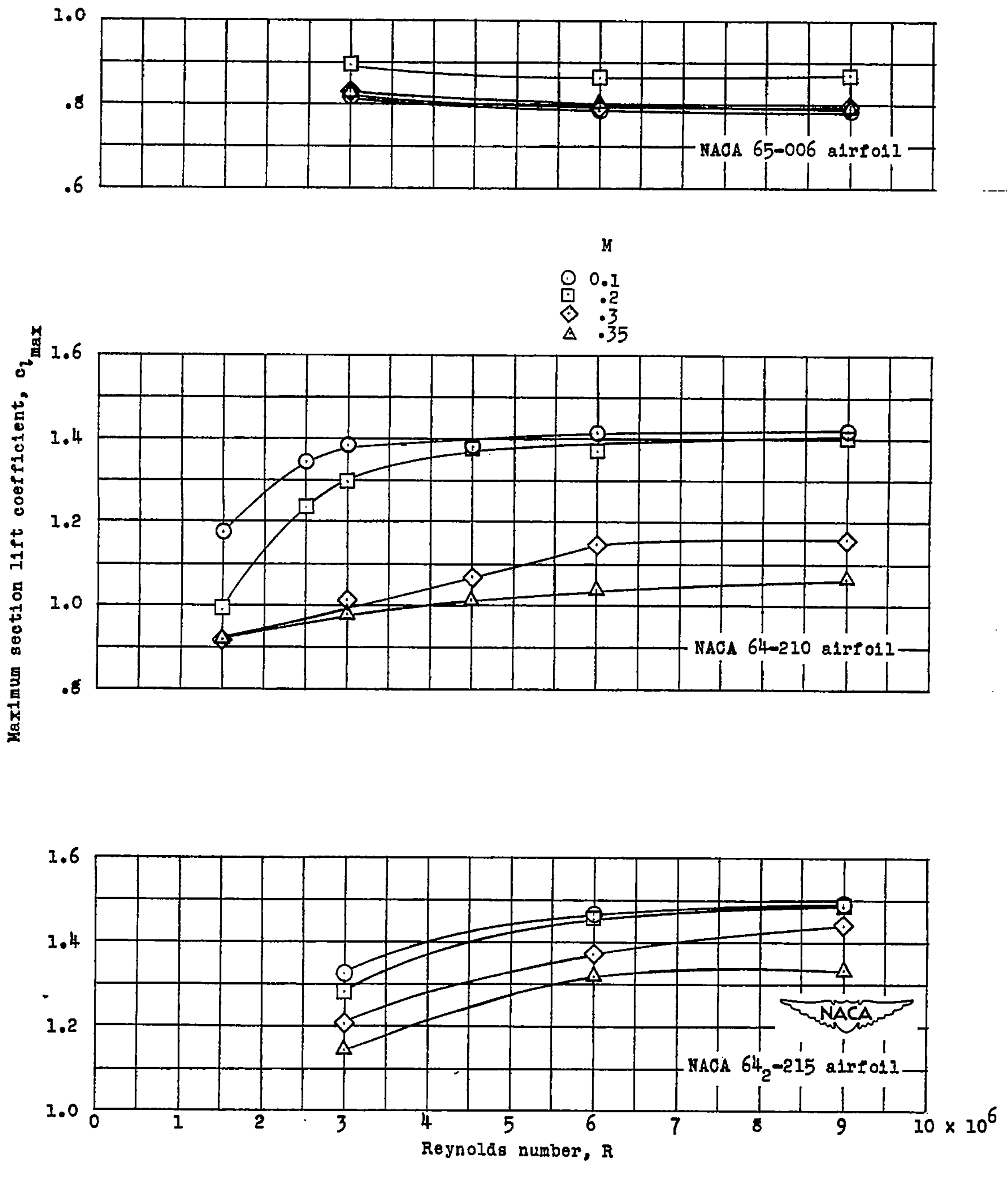
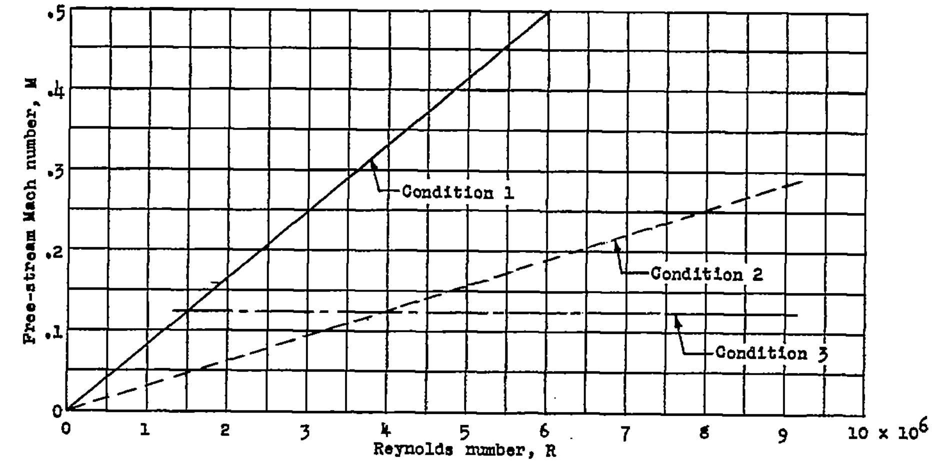
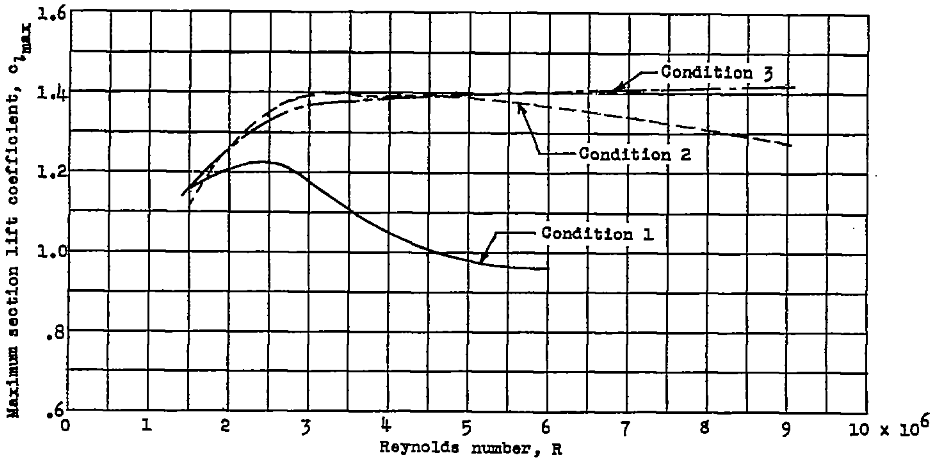


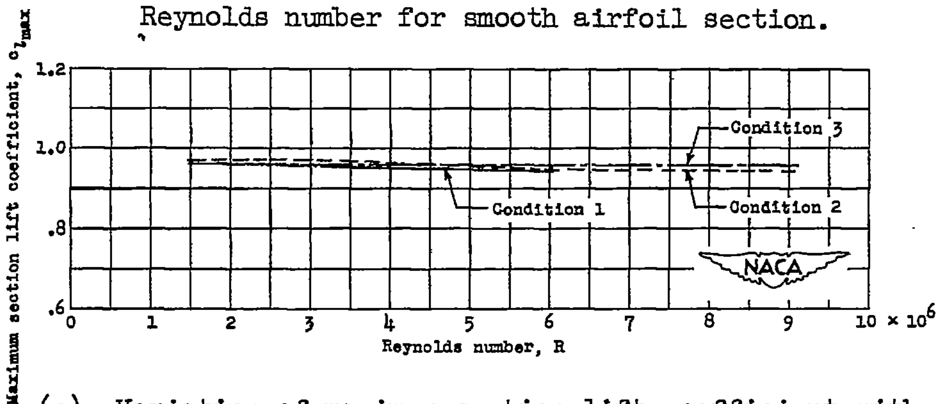
Figure 7.- Variation of maximum section lift coefficient with Reynolds number for several free-stream Mach numbers. Smooth condition.



(a) Assumed variations of Mach number with Reynolds number.

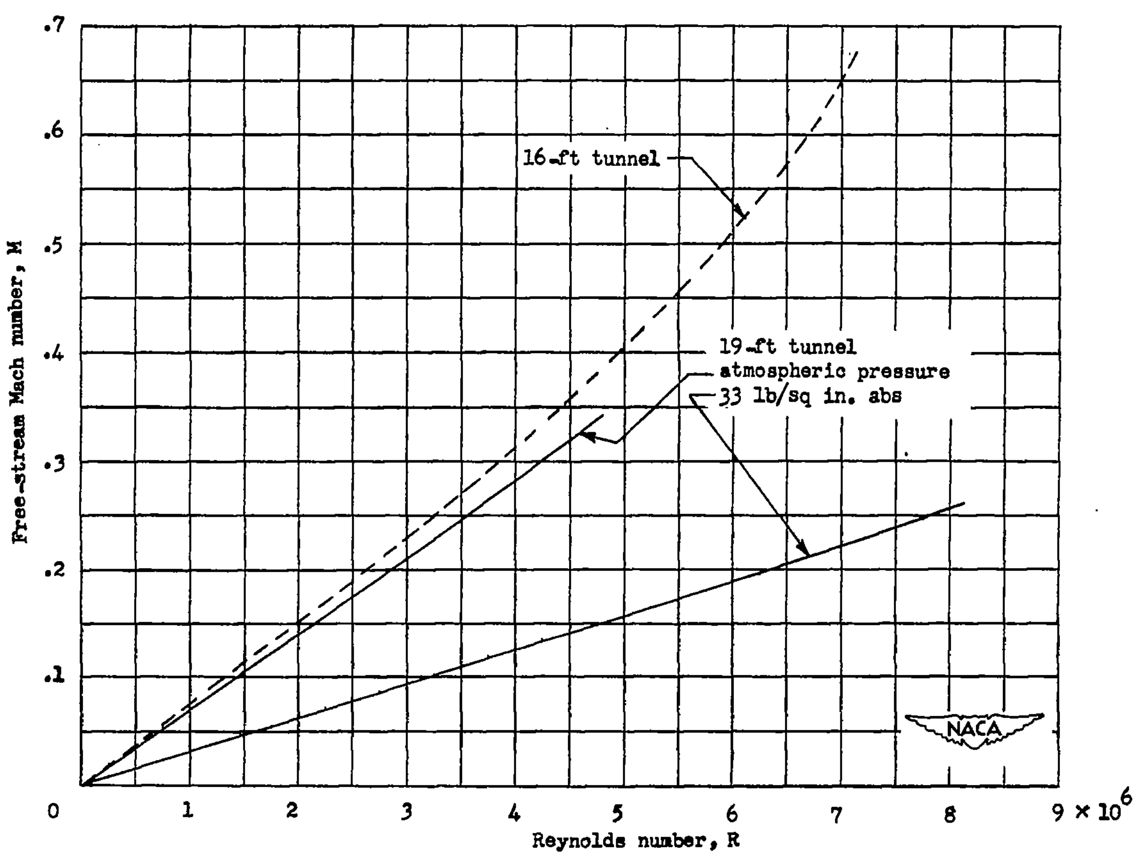


(b) Variation of maximum section lift coefficient with Reynolds number for smooth airfoil section.



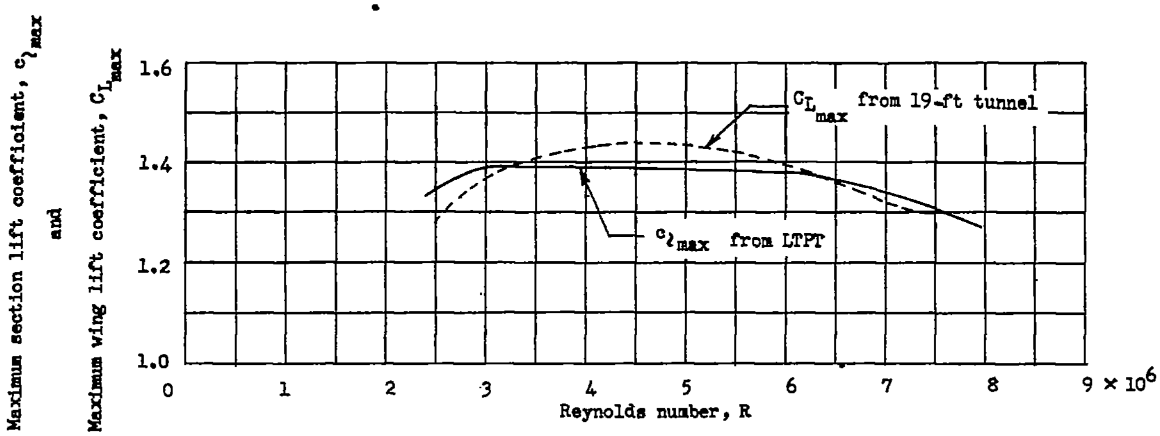
(c) Variation of maximum section lift coefficient with Reynolds number for airfoil section with leading-edge roughness.

Figure 8.- Variation of maximum section lift coefficient with Reynolds number for the NACA 64-210 airfoil section for three assumed variations of Mach number with Reynolds number.

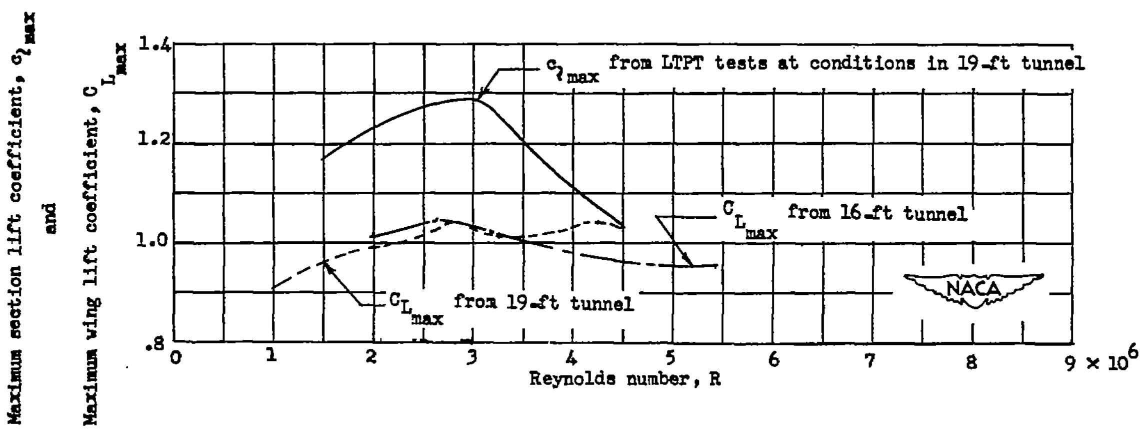


(a) Variation of Mach number with Reynolds number for tests of wing with aspect ratio of 6, taper ratio of 2.1, mean aerodynamic chord of 2.07 feet, and NACA 64-210 airfoil sections. Data obtained from Langley 19-foot pressure tunnel and Langley 16-foot high-speed tunnel.

Figure 9.- Comparison of data obtained from tests of two-dimensional model of NACA 64-210 airfoil section in Langley low-turbulence pressure tunnel (LTPT) with data obtained from tests of wing of NACA 64-210 airfoil section in Langley 19-foot pressure tunnel (ref. 13) and Langley 16-foot high-speed tunnel (ref. 7).

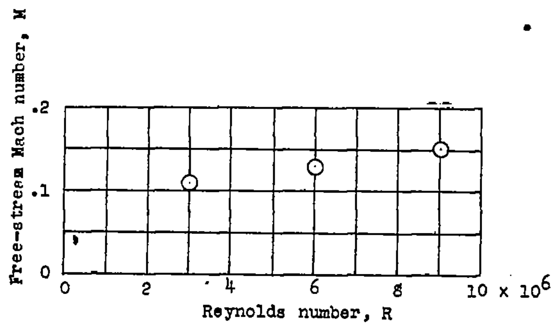


(b) Variation of maximum wing lift coefficient and maximum section lift coefficient with Reynolds number for conditions in Langley 19-foot pressure tunnel at 33 pounds per square inch absolute.

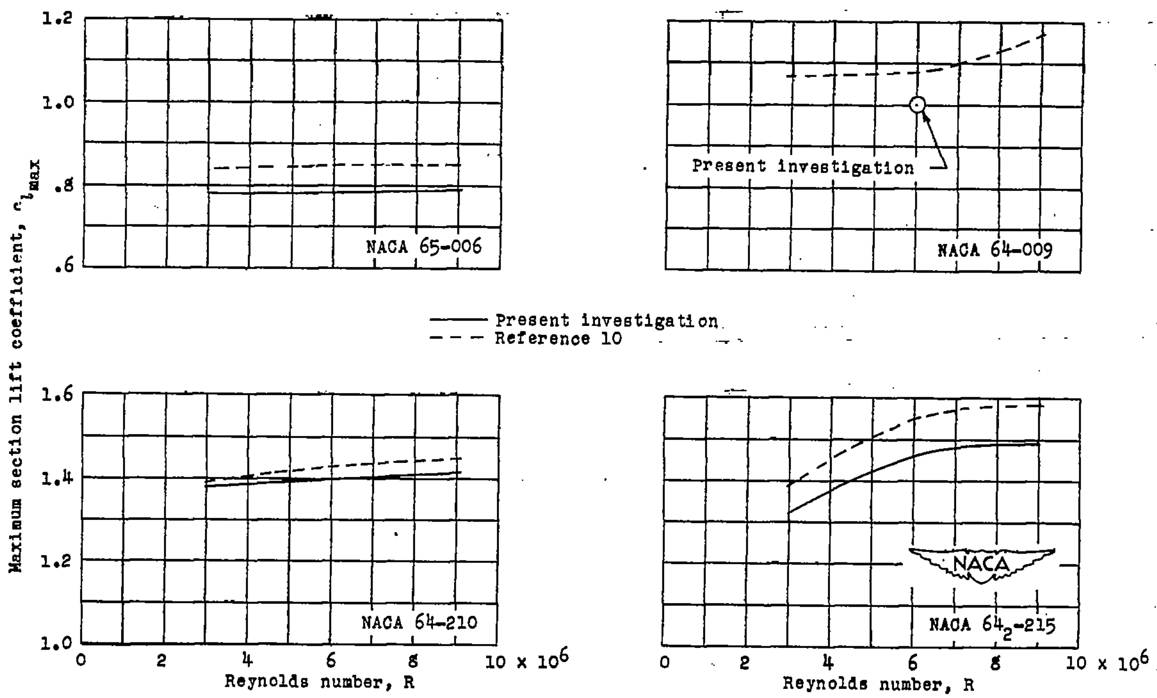


(c) Variation of maximum wing lift coefficient and maximum section lift coefficient with Reynolds number obtained from tests in three tunnels. Langley 16-foot high-speed tunnel and Langley 19-foot pressure tunnel at atmospheric pressure.

Figure 9.- Concluded.



(a) Approximate free-stream Mach numbers for the two-dimensional investigations of 2-foot-chord models reported in reference 10.



(b) Variation of maximum section lift coefficient with Reynolds number.

Figure 10.- Comparison of maximum section lift coefficients obtained from present investigation with those obtained from reference 10. Models in smooth condition.

NACA-Langley - 11-10-52 - 1000